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IMPLEMENTATION OF AMPLITUDE MODULATION COMPANDING IN THE BBC MF NATIONAL NETWORKS

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THE BRITISH BROADCASTING CORPORATION

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Summary

The introduction of new transmitter designs in the LF, MF and HF broadcast bands has not only improved efficiency directly, but permitted use of modulation-dependent control systems which can themselves further reduce operating costs without loss of coverage.

This Report describes the design and development of one such modulation-controlled system, known as Amplitude Modulation Companding (AMC). In this method both carrier and sideband levels are progressively reduced as the modulation level is increased, this effect being compensated in the receiver by the normal action of the automatic gain control circuit. Extensive trials of a fully developed system for 50 kW MF transmitters have achieved input power savings of between 20% and 40%, depending on programme content. This is achieved with imperceptible loss of coverage and further savings may be practicable.

Engineering Division,
BRITISH BROADCASTING CORPORATION

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1. INTRODUCTION

1.1 General

Double-sideband amplitude modulation (DSB) has played a major role since the start of radio broadcasting, being the modulation system adopted in the LF, MF and HF bands. Over the years in these bands, the need to increase coverage, or even retain existing coverage in the presence of increased interference levels, has resulted in the use of progressively higher transmitter powers. This, associated with the rising cost of electricity, has led to an increasing interest in economising on transmitter running costs whilst maintaining coverage and standards of quality.

Two methods of achieving such economies exist. These are:-

(1) Improvement of transmitter operating efficiencies by techniques such as switched mode (class 'D') RF amplification, pulse duration modulation (PDM) and impedance modulation (Doherty) systems.

(2) Dynamic regulation of the transmitter output or dynamic carrier control (DCC) according to the level of the applied modulating signal.

These methods are interdependent to the extent that it is the developments in transmitter design represented by (1) which make the dynamic regulation in (2) feasible.

In all three bands the BBC has already taken account of (1) by means of an extensive programme of modernization. This Report therefore deals with (2). Here, two techniques are well known[1,2]. These have a degree of similarity, but differ in their basic principle of operation.

In one case the carrier level for low modulation conditions is set below its full modulation value and increased dynamically to accommodate high levels of modulating signal; in the other, normal operation occurs at low modulation levels and the complete modulated output of carrier and sidebands is reduced in amplitude (i.e. compressed) at high modulation levels. The former method is usually known as Dynamic Amplitude Modulation (DAM) and the latter as Amplitude Modulation Companding (AMC).

1.2 Dynamic Amplitude Modulation (DAM)

This method of dynamic control was first proposed in 1939[3] and has been in operation at MF in some European countries for a number of years. In this method the carrier power is reduced, typically by about 40%, for modulation levels up to about 50% thereafter increasing to give the full output level at 100% modulation. The system may also be referred to as Dynamic Pulse Duration Modulation (DPDM)[4].

Although this method is understood to be successful, it is considered to have a fundamental disadvantage, namely that under conditions of low modulation, when the wanted signal is most vulnerable to noise and interference it has a reduced level. Whereas this is considered to be partially compensated by the additional compression provided by the receiver automatic gain control (AGC), this must presumably be associated with a reduction in the compression previously applied if there is to be no reduction in quality. Theoretical investigations indicate that a reduction of about 1 dB in wanted-to-interfering signal ratios can be expected[3].

1.3 Amplitude Modulation Companding (AMC)

This method has been developed by the BBC[2,5,6] and differs from DAM in that the compression is increased approximately linearly from zero in the unmodulated condition to a maximum value at 100% modulation, whilst maintaining the appropriate depth of modulation. This is seen as having the following advantages:-

i) Receiver AGC operation compensates for the applied compression.

ii) The reduction of peak voltages and powers allows further savings due to redesign of the transmitter output stages; reduced peak demand may allow lower electricity charge rates. For new installations the reduced peak voltages may allow a derating of antennas and feeders.

iii) Maintenance of normal power levels during periods when the programme content is most susceptible to interference, i.e. under conditions of low modulation.

iv) As an alternative to (ii) if the operating power is determined by peak conditions,

and improved coverage is more important than electricity savings, it may be possible to operate transmitters at increased levels of mean power.

This Report summarizes the work carried out within BBC Engineering Division on development and implementation of AMC within the MF National Networks. In particular it covers:-

i) Initial laboratory tests by Research Department and subsequent over-air tests in conjunction with Transmitter Capital Projects Department (TCPD), Transmitter Operations and Maintenance, and Radio Broadcasting.

ii) The design of a digital compressor module by Design and Equipment Department.

iii) Assessments of potential savings in relation to a modern 50 kW MF transmitter based on tests carried out at Brookmans Park by TCPD and Transmitter Technical Services.

iv) The results of field trials with AMC applied to the Radio 2 transmissions from Brookmans Park on 909 kHz.

v) Experience of operational use of AMC at Brookmans Park.

2. AMC PRINCIPLES AND INITIAL EXPERIMENTS

2.1 Basic principles

Fig. 1 shows modulation envelope waveforms illustrative of conventional double-sideband amplitude modulation transmission. Fig. 1(a) indicates the unmodulated carrier and Figs. 1(b), (c) and (d) the envelope for a sinusoidal modulating signal at modulation indices (m) of approximately 0.1, 0.5 and 1.0 respectively. The radiated power for sinusoidal modulation increases with modulation index (m) according to the law $1 + m^2/2$ and at full modulation reaches 1.5 times the power of the unmodulated carrier.

The radiated signal is demodulated at the receiver to reproduce the sound programme. Modern receivers incorporate an AGC system which generally responds to the mean level of the radio frequency (RF) carrier. The AGC is arranged, within its range of control, to keep the level of modulated signal substantially constant at the demodulator, irrespective of the level of the signal at the aerial. The AGC action thus tends to equate the reproduced levels of programmes radiated from various transmitters which provide differing signal strengths at the receiver, and further, to compensate for the effects of fading on the propagation path between transmitter and receiver.

In the AMC system being considered, the transmitter output signal is compressed syllabically according to some chosen law as the level of modulation is increased. This action is specifically arranged to ensure that the modulation index is the same as for a conventional system throughout the full modulation range. The effect is indicated in Fig. 2, which shows the output envelope waveform of an amplitude-compressed system, using for illustration, a particular control characteristic which maintains the maximum peak output voltage constant. Figs. 2(b), (c) and (d) indicate output waveform envelopes for sinusoidal modulation at modulation indices of about 0.1, 0.5 and 1.0 respectively.

Comparison between Fig. 2 and Fig. 1 shows that conventional modulation indices have been maintained despite the compressor action. The natural control action of a conventional receiver AGC system tends to offset the variations of transmitter output power, and thus ensures that the audio programme is reproduced throughout with appropriate relative levels.

The overall arrangements, comprising compression at the transmitter and compensatory expansion by the receiver AGC circuits, in fact constitutes a pilot tone compander, where the pilot tone is actually the RF carrier.

2.2 Potential sources of programme quality impairment

Because the transmitter/receiver combination operating as described in this Report, constitutes a compander, attention must be given to the possible introduction of impairments caused by the companding action.

First, there is risk of subjective impairment due to a disturbance of the balance of relative programme levels. This can occur in steady state if the accuracy of expander tracking is not adequate, or momentarily if tracking is not sufficiently rapid to avoid audible disturbance of the reproduced programme while the programme level is changing.

In an AMC system the expander characteristic is determined by the receiver AGC so is not under the control of the broadcaster. However, measurements on a number of AM receivers*, and laboratory listening tests suggest that quality impairment due to level perturbation is unlikely to be a problem.

* See Section 2.4 and Appendix 1.

Fig. 1 - Modulation envelope of a normal amplitude modulated transmission.

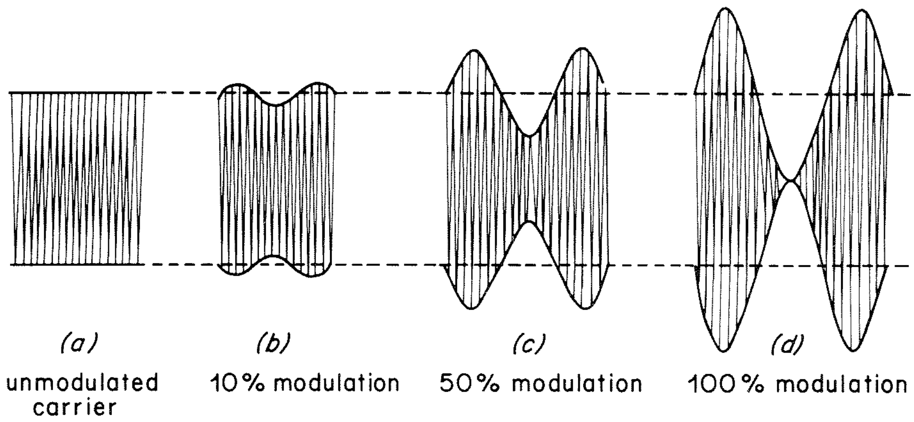
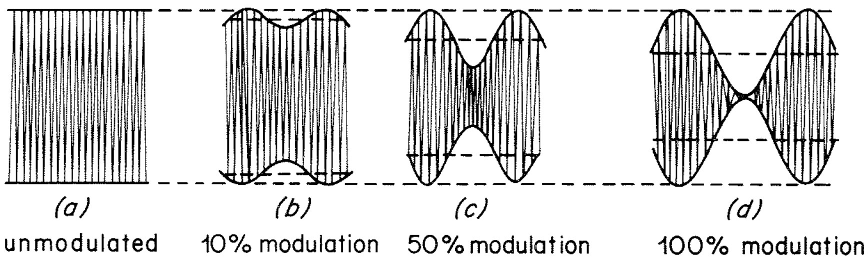


Fig. 2 - Modulation envelope of a transmission incorporating Amplitude Modulation Companding. The figure shows a particular case having a maximum compression of 6 dB.



A second potential source of impairment in a companding system results from the possible effects of noise and interference. In all companding systems the higher level audio signals, which cause such companding action, themselves tend to mask the increased levels of noise and interference. Impairment due to programme-modulated interference will only occur when interference is present (i.e. under adverse reception conditions) and its effect will not be great when, as proposed, the amount of compression/expansion introduced is relatively small.

2.3 The transmitter as a compressor

2.3.1 Static considerations

The output compression characteristic required to produce a constant peak output voltage characteristic (Fig. 2) can readily be achieved in a low power implementation by a circuit arrangement such as that indicated in Fig. 3.

The arrangement comprises essentially, two modulators in cascade; the first, M1, operates conventionally and feeds a normal amplitude modulated signal to one input of the second modulator, M2. This second modulator, in addition to providing the signal to be radiated, feeds a control chain, C, in which the signal is rectified, peak detected, referred to a 'threshold' level reference and passed through attack/recovery-rate control circuits back to its second input.

Fig. 3 illustrates a circuit arrangement in which compression is output-controlled with the control signal, Vc, derived from the radiated signal. Compression can equally well be input-controlled, with Vc derived from the audio input signal and a DC component added, as appropriate, to set the level of the quiescent carrier. Such an arrangement is illustrated

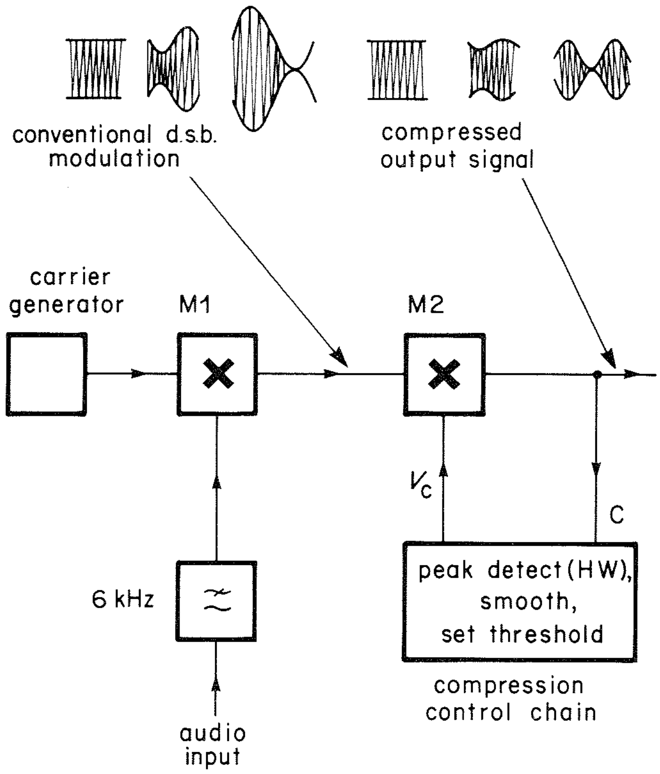


Fig. 3 - 'Output controlled' AMC system.

in Fig. 4, which indicates the provision of controls for the carrier level, the amount of compression and the compression threshold (i.e. the modulation index value at which compression begins). The use of input control considerably increases the flexibility of the system and enables the control law to be changed more simply.

in Fig. 1(d). Thus the peak level of radiated signal is allowed momentarily to exceed its ultimate value but it is thereafter rapidly reduced to that level as compression is imposed.

If, however, some advantage in terms of component rating is being taken in reducing the required output voltage swing, even this momentary peak of output signal amplitude cannot be allowed. The necessary characteristics can readily be achieved by means of non-overshoot delay-line limiter techniques[7].

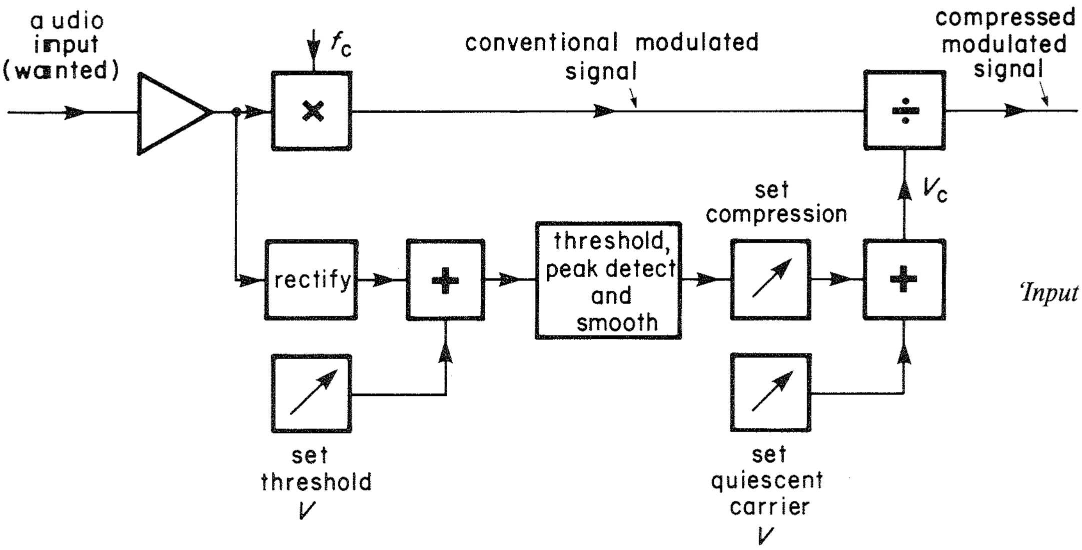


Fig. 4
'Input controlled' AMC system.

2.3.2 Dynamic considerations

The circuits of Figs. 3 and 4, and indeed their modes of operation, are essentially similar to those of a simple, syllabic, sound-signal limiter, and the dynamic characteristics established for such limiters[6] give an indication of the requirements for the RF radiation compression circuits now being considered and discussed in detail in Section 3.

In practice an attack time of about 0.3 ms and a recovery time option of some 125 ms to 250 ms were provided in the experimental equipment. Use of a shorter attack time increases the risk of quality impairment due to over-rapid control[6], while an increase would either lengthen the period of signal overshoot in a simple control arrangement, or demand an increase in the audio signal delay time in the non-overshoot input-controlled arrangement discussed below.

Selection of recovery time did not appear to be critical, but, laboratory tests using a number of conventional receivers indicated a recovery time of about 200 ms to be appropriate.

Where the transmitter can accept 100% modulation, operating conventionally, the transition in the compression mode with increasing modulation — in the limit from no modulation to full modulation, i.e. from the state represented by Fig. 2(a) to that of Fig. 2(d) — can be made via the condition illustrated

Here, an audio-signal delay circuit is included in the audio input to the variable-gain path, but not in the feed to the circuits in which the control signal is derived. By this means the gain in the variable-gain element can be reduced appropriately in anticipation of the arrival of a high-level audio signal, and signal overshoot at the system output can thereby be eliminated.

The arrangements indicated in Figs. 3 and 4 have been implemented at low power for laboratory experiments. However, the required operating characteristics have also been achieved for high-power application as discussed in Section 3.

2.4 The receiver as an expander

The deliberate compression of the radiated signal envisaged in the AMC system amounts to only a few decibels, where receiver AGC circuits are designed to operate over a wide range of levels. However, although the range of static AGC control provided should be adequate there is the further requirement that dynamic tracking should be sufficiently rapid. When, for example, the transmitted signal is rapidly compressed the demodulated receiver

output will momentarily be lower than it should have been, recovering to the correct level only as the AGC responds to the change in signal strength. Conversely, as the radiated signal recovers from compression (i.e. as the depth of modulation falls) the demodulated output will tend to be high until the AGC circuit has reached equilibrium. The AGC characteristics of some fourteen receivers of different manufacture were examined within their effective AGC ranges, using as a test signal an RF carrier with about 50% modulation, the whole being switched repeatedly between two levels 6 dB apart. The action of the receiver AGC was then assessed in terms of the gain fluctuation characteristics of the demodulated output.

In the receivers examined the mean time taken for the AGC to restore gain to within 2 dB of the final steady state, following the abrupt reduction of applied signal level, was about 20 ms. Where the full amount of control being effected is small, this transient level discrepancy seems unlikely to be obtrusive.

The AGC equilibrium following an abrupt increase in signal level was in the cases examined, substantially restored within a few tens of milliseconds. Since the transmitter compressor recovery time envisaged is of the order of 200 ms, AGC tracking during this phase of operation will be extremely close and no impairment due to mistracking is to be expected.

Subsequent to the field trials discussed in Section 5 tests of AGC performance of a further seven receivers were carried out and are discussed in Appendix 1.

3. SUBJECTIVE EVALUATIONS

3.1 Laboratory listening tests

The apparatus used in the laboratory at this stage was essentially that indicated in Fig. 3, giving a maximum of 6 dB compression at 100% modulation. Additionally, means were provided for introducing interfering signals at controlled relative levels, and for a ready comparison of the companding arrangement with a conventional system having the same quiescent carrier power for reference.

Demonstrations were given to a considerable number of listeners, using a range of receivers to assess the effects of gain fluctuation in good reception conditions i.e. the effects of inadequately compensated compression. The consensus was that degradation was minimal and could therefore be ignored.

The effects of programme-modulated interference were demonstrated by introducing modulated co-channel and adjacent-channel interfering signals. Under adverse, but still 'acceptable' listening conditions, the companding system was generally considered to be not significantly worse than the conventional system.

3.2 Preliminary over-air tests

In view of the generally encouraging laboratory tests, it was decided to carry out some over-air tests to obtain an indication of system performance under a wide range of practical reception conditions. The transmitters concerned were modified to produce the desired compression operation and to switch to normal AM as the reference.

On the basis of some preliminary tests it was decided to proceed with this stage of the investigation using two laws giving 1.1 dB and 2.7 dB maximum compression respectively. The performance of AMC using these compressions was compared with conventional AM by switching continually between conditions in arbitrary order of presentation over a single half-hour period during late evening. Listeners were asked to indicate their preferences using a CCIR 7-point comparison scale having negative gradings indicating a preference for conventional AM.

The results of the AMC over-air tests are given in Table 1 which lists the mean gradings and standard deviations for various programme items and for the two compression laws. Column (a) gives the overall results and Columns (b) and (c) give the corresponding data for those listeners who noted the presence of interference, and those who did not, respectively.

These results were encouraging and suggest that no general pronounced degradation of performance would result from the introduction of AM compression using either of the laws tested.

3.3 Comparisons with fixed power reductions

Bearing in mind that an alternative means of achieving power savings at AM transmitters is merely to reduce the operating power it seemed important to compare subjective quality degradations resulting from using AMC to those which would result from a fixed power reduction. Laboratory assessment tests, involving twelve listeners, were carried out to make this comparison and are discussed in detail in Appendix 2. The following principal conclusions can be drawn:-

i) With AMC, impairments were more noticeable under noise-limited rather than interference-limited conditions. This difference was less noticeable with fixed power reductions.

ii) Averaging the results for all the listeners and for the four types of programme content a static power reduction of 1 dB was imperceptible to 90% of listeners. This same perceptibility limit (i.e. 10%) corresponded to AMC with maximum compressions of about 3 dB and 7 dB in noise-limited and interference-limited conditions respectively.

iii) Unfortunately, the range of AMC compression available (maximum value = 10 dB) was not sufficient to allow corresponding averages to be obtained at the level for which impairment was imperceptible to only 50% of listeners.

However, for this condition :-

a) in the interference-limited case, a fixed reduction of 2 dB corresponded to AMC with a maximum compression in excess of 8 dB;

b) in the noise-limited case, a fixed reduction of 1.5 dB corresponded to AMC with a maximum compression in excess of 5.5 dB.

3.4 'Mush-Area' laboratory tests

The quality-impairment tests previously described, involving co-channel interference, were on the basis of different wanted and interfering programmes. However, the BBC National Networks at MF use synchronised operation such that, in daytime, coverage can be limited by co-channel transmissions carrying the same programme. The zone of mutual interference in such cases is normally termed a 'mush area' and might be affected if one or both transmissions used AMC.

Laboratory tests to investigate this were carried out, first repeating Whythe's[8] experiments in order to establish a reference condition of an AM signal with interference from another AM signal. This was then repeated for an AM signal with interference from an AMC signal (AM/AMC) and vice versa (AMC/AM). Fig. 5 is a block diagram of the equipment used for these tests, which were carried out with a maximum AMC compression of 3.5 dB.

The results of the mush-area tests indicated that the gradings for speech and music were generally comparable with the AM/AM reference, except that the results were slightly worse, by approximately 0.4 of a grade for the AMC/AM speech tests. This slight degradation was not noticeable in the music tests and

Table 1
Preliminary Over-Air Tests – Mean Grading (Standard Deviation)*

Programme	Maximum compression (dB)	(a) Overall	(b) Interference mentioned (13 results)	(c) Interference not mentioned (10 results)
Speech	1.1	−0.13 (0.96)	−0.23 (0.94)	0 (1.04)
	2.7	−0.07 (1.05)	−0.12 (1.19)	0 (0.95)
Soprano	1.1	+0.04 (0.91)	0 (0.83)	+0.10 (1.11)
	2.7	−0.70 (1.15)	−1.00 (1.01)	−0.30 (1.26)
Piano	1.1	+0.17 (0.82)	−0.08 (0.87)	+0.50 (0.70)
	2.7	−0.13 (1.15)	−0.31 (1.12)	+0.10 (1.20)
All items	1.1	+0.03 (0.91)	−0.10 (1.01)	+0.20 (1.14)
	2.7	−0.30 (1.16)	−0.47 (1.30)	−0.07 (1.26)

* 7 Point Comparison Scale

+3 B much better than A
+2 B better than A
+1 B slightly better than A
0 B same as (or equivalent to) A
−1 B slightly worse than A
−2 B worse than A
−3 B much worse than A

where A corresponds to conventional AM
B corresponds to AMC

it is considered that the protection ratio, for common programme/common frequency working using AMC remains substantially the same as that for conventional AM.

In view of the above results and taking into account the inherently time-variable nature of interference occurring in a practical situation, it is considered unlikely that there will be any reaction, favourable or otherwise, from listeners in mush areas.

overshoot free then undesirable gain reduction effects can be created when the compressor is presented with high amplitude transients. Transient overmodulation of the transmitter could also occur.

To provide overshoot-free operation the audio signal must be delayed ahead of the variable gain element, so that by the time the signal reaches it the gain reduction effected by the control circuits is complete.

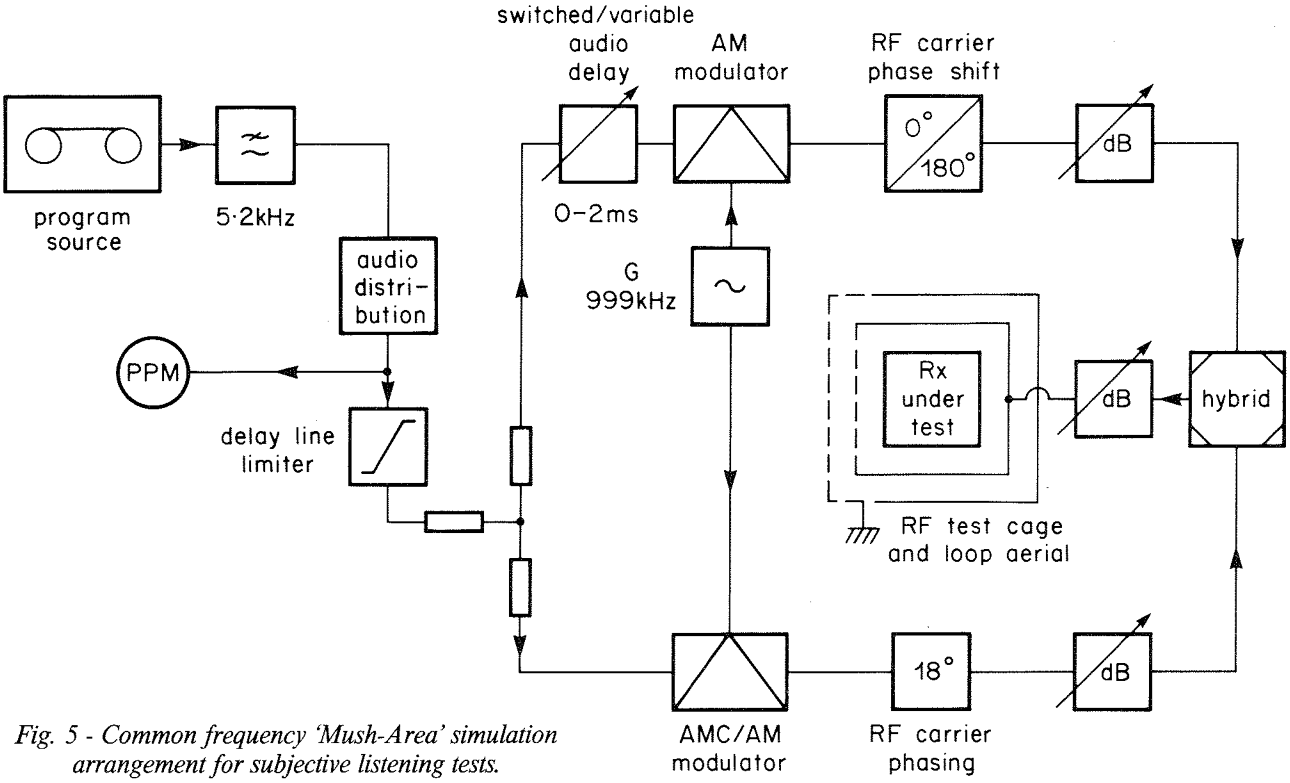


Fig. 5 - Common frequency 'Mush-Area' simulation arrangement for subjective listening tests.

4. REQUIREMENTS AND DESIGN OF A DIGITAL COMPRESSOR

In order to apply AMC to a transmitter it is necessary to provide preprocessing of the audio signal at the transmitter. This processing is required to produce up to 6 dB of audio compression at 100% modulation together with an accurately tracking DC voltage to control the transmitter carrier level.

This voltage is proportional to the linear amplitude compression rather than to the logarithmic law usually associated with commercial voltage controlled amplifiers (VCAs).

A consequence of having finite time constants in the control path of a compressor means that the output could exceed the steady state value which would have been achieved with a constant input level, i.e. 'overshoots' may occur. If the compressor is not

The above requirements can be readily met by using digital processing techniques. One device having an audio output which is exactly proportional to a control voltage is the multiplying digital-to-analogue converter (DAC). In this device the audio performance is accurately defined by its specific resolution. Although the DAC and the required analogue-to-digital converter (ADC) are more expensive than the alternative four-quadrant multiplier, the use of the ADC/DAC combination results in accurate tracking with easy and stable alignment.

A further bonus is that the audio delay required for overshoot-free operation can be easily implemented in cheap random access memory (RAM). Also digital units are very similar to each other in performance. This is of importance in BBC installations where it is common practice to put two or more transmitters in parallel to achieve the required output power.

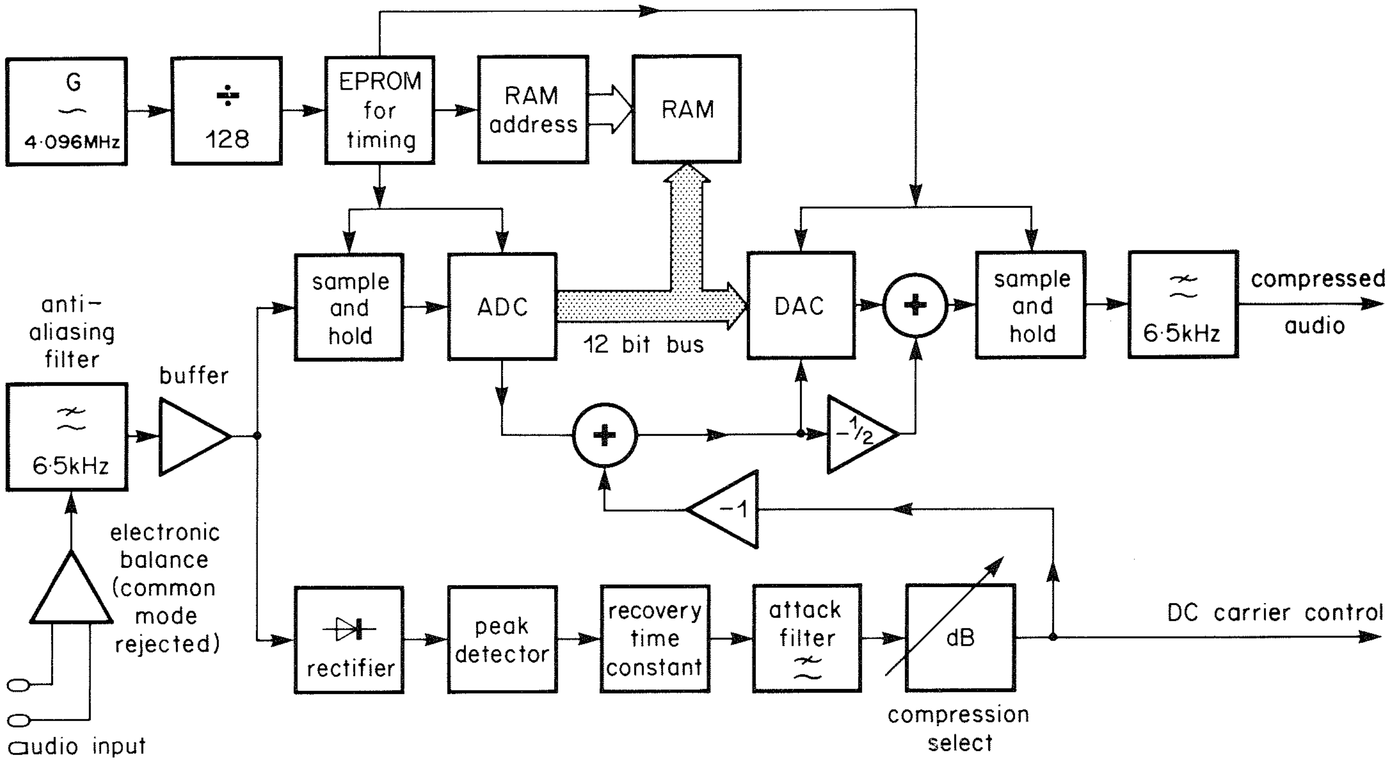


Fig. 6 - AMC Companding Unit (AM6/30): Block diagram.

Fig. 6 shows a block diagram of such a compressor designed by BBC Design and Equipment Department and designated 'AM Companding Unit' (AM6/30). A brief description of the circuit is given below.

The audio input signal is fed to an electronic balance circuit designed to reject common-mode signals. This is necessary in order to alleviate any problems which might occur in a high RF field situation such as near high-powered transmitting or antenna equipment.

The next stage is a fourth-order Chebychev 6.5 kHz low pass filter with an insertion loss of approximately 45 dB at 16 kHz (half sampling frequency). After buffering the filtered audio is divided between the control chain and the audio processing chain.

In the control chain the audio signal is full-wave rectified, peak detected and smoothed. The peak detector must be fast enough to deal with any transients which the input filter allows through. The signal is then fed through the attack filter and the compression select attenuator. An attack time of either 0.3 ms or 5 ms can be selected and a preset recovery time of either 120 or 240 ms is available. The attenuator allows different levels of compression to be set, the range of compression available being 6 dB in 0.5 dB steps. The output signal is used to control the carrier level of the transmitter. This signal is also used to control the voltage controlled amplifier in the audio processing chain described below.

In the audio processing chain the signal is fed via a sample-and-hold circuit to the 12-bit analogue-to-digital converter and the digitised samples are read into RAM which provides the necessary delay for overshoot-free operation. Timing and control waveforms are provided by a sequencer formed by a counter and an erasable programmable read only memory (EPROM). The 32 kHz sampling frequency clock is derived from a 4.096 MHz oscillator.

The DAC is configured to work as a linear voltage-controlled amplifier (VCA). The output voltage of the VCA is the product of the reference voltage and the digital number supplied to it. In this circuit the reference voltage is the sum of the DC reference generated by the ADC and the inverted signal derived from the control chain. The digital code produced by the ADC is offset binary, hence it is necessary to subtract half the DAC reference from the DAC output which would otherwise contain unwanted DC. The DAC signal is then passed to a sample and hold circuit and a 6.5 kHz anti-aliasing filter, this filter being a seventh-order elliptic function type. The output of the filter is the compressed audio, the level of compression being set by the control chain output.

Fig. 7 is a photograph of the AM6/30 AM-companding unit, which was used to apply AMC to the BBC's Marconi B6034 transmitters.

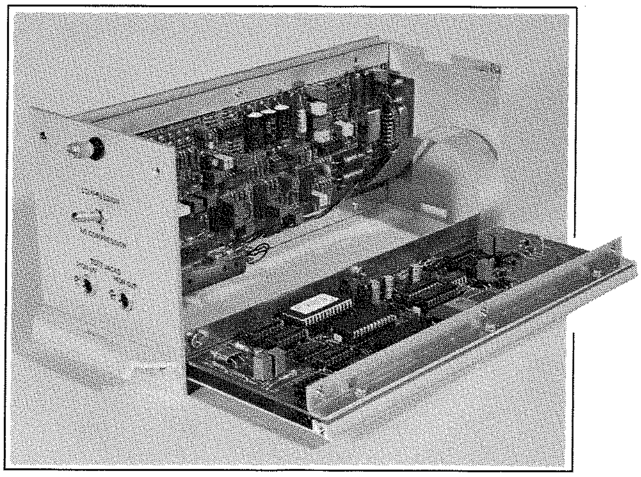


Fig. 7 - AMC Companding Unit (AM6/30): Construction

5. AMC TESTS ON 50 kW AM TRANSMITTERS

5.1 Introduction

Following earlier field trials of AMC applied to transmitters at Brookmans Park, further testing was arranged to:

(i) satisfy Transmitter Department that the proposals to implement this on B6034 type 50 kW MF transmitters were practicable from an operational viewpoint;

(ii) obtain further data on power savings achievable from AMC; and

(iii) obtain data for comparative savings by fixed power reduction. Tests were conducted on two 50 kW MF type B6034 transmitters operating on 909 kHz and 1458 kHz.

5.2 Test programme material

Three types of material were used for comparative power consumption measurements, the object being to achieve repeatable signals for any measurement. They are:

P1 - The normal BBC Radio 1 popular music signal as radiated from Brookmans Park. It consists of heavily-compressed audio material in which the form factor does not vary significantly during any period of measurement.

P2 - A Compact Disc player, operating in a continuous repeat mode was used to provide popular male vocal music. 12 dB of limiting was provided by an AM6/18 delay-line limiter in which the 'Auto' recovery time constant was selected.

P3 - This was similar to P2 except that a classical orchestral music disc was employed and the limiting level was 8 dB.

5.3 Power measurements

Power consumption was determined by running the transmitter over long periods of time, usually for durations of seven to twenty hours, and measuring a mean kilowatt/hour rate.

AC mains input was measured using a Supply Authority type integrating watt meter.

The transmitter output was coupled into a known resistive test load (VSWR 1.04) and the power determined by means of a precision rectifier-type RF ammeter. As a back-up, the transmitter has its own output (forward power) meter.

5.4 Reference conditions

Tests were made for each of the three programme types with the transmitter in an unmodified condition. In addition to 'reference' consumption and efficiency measurements, the transmitter was also tested for its general performance under various conditions, e.g. mains voltage variation.

Later, another series of tests were performed with the transmitter unmodified, but with the controls optimised for maximum efficiency. Under these ideal conditions, however, it was considered that the transmitter may not necessarily operate satisfactorily or reliably into a real antenna as opposed to the test load.

5.5 Abnormal conditions

Whilst it is nearly always possible to make a transmitter show a respectable performance under ideal conditions, this may not be the case during periods of extreme mains voltage or other abnormal conditions. To take account of this, the transmitters were tested extensively in order to predict their behaviour.

The station diesel alternator was used as a means of applying the specified +6% to −10% mains voltage and the test load impedance was varied up to the normal protection level. The nominal fifty ohms resistive load was altered by adding inductance or capacitance to produce corresponding VSWRs of 1:1.45 and 1:1.35.

Excessive input signal causing overmodulation did not result in operation of any protective circuits. Similarly when a test disc containing a wide repertoire of test signals, including square waves at 5 Hz, was applied via the AM6/18 limiter, the transmitter did not trip or behave abnormally.

Stability was demonstrated successfully by removing RF drive whilst modulating at various levels.

5.6 Summary of energy saving measurements

5.6.1 AMC operation and fixed power reduction (FPR) up to 3 dB

Table 2 summarizes the energy savings in kilowatts obtainable for each 50 kW transmitter for various programme types and operating modes.

Table 2
Energy Savings in kW

Programme Type*	Ideal Reference Condition†	Typical Reference Condition†	Operating Mode
P1	39	43	3 dB AMC
P2	22	25	3 dB AMC
P3	16	18	3 dB AMC
P1	20	24	2 dB FPR
P2	22	25	2 dB FPR
P3	23	25	2 dB FPR
P1	47	51	3 dB FPR
P2	38	41	3 dB FPR
P3	40	42	3 dB FPR

* as described in Section 5.2
† reference conditions discussed in Section 5.4

The savings anticipated for BBC programmes are slightly below P3 for Radio 3 and between P1 and P2 for Radio 2. P1 is equivalent to Radio 1.

5.6.2 AMC operation with 6 dB maximum compression

The field trials described in the following section indicated that a maximum compression of 3 dB will provide negligible loss in reception quality even in fringe areas. The energy saving tests were therefore extended to cover the case where the maximum compression is increased to 6 dB.

Fig. 8 indicates the comparison between AMC with maximum compression up to 6 dB and fixed power reductions up to 3 dB for a range of modulation indices, derived from Table 2 and assuming the peaking valve to be retained for the 6 dB AMC condition.

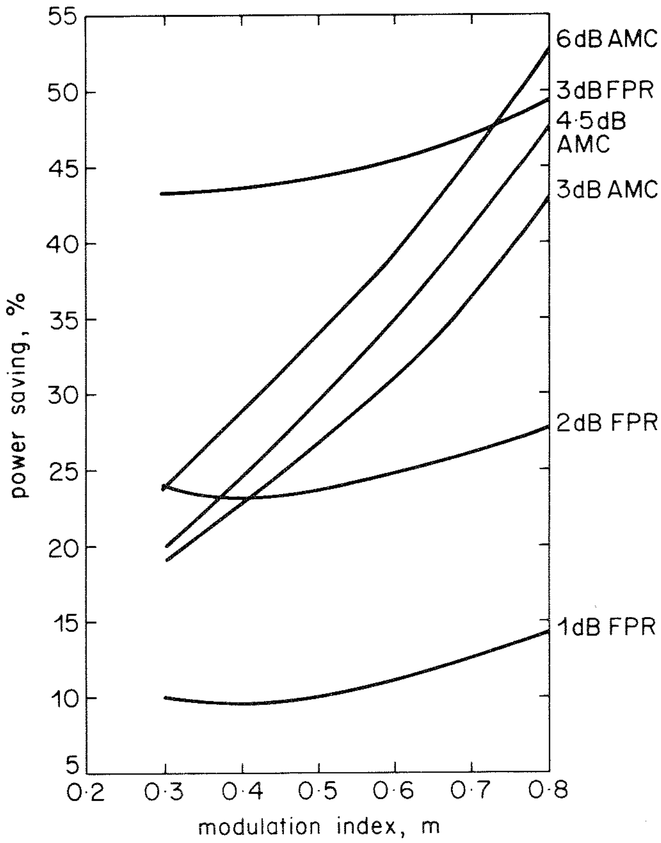


Fig. 8 - Results of power saving tests at Brookmans Park and Droitwich.

6. THE RESULTS OF FIELD TRIALS WITH AMC APPLIED TO THE 909 kHz TRANSMITTERS AT BROOKMANS PARK (LONDON) AND CLEVEDON (SOMERSET)

6.1 General description

The success of the initial field trials and the confidence gained in the system from the laboratory mush area simulation, led to a more elaborate field trial being undertaken. The 909 kHz Radio 2 transmitters at Brookmans Park and Clevedon were modified by TCPD and Transmitter Department using the digital compression modules designed by Design and Equipment Department described earlier.

The trials primarily involved the application of AMC to the Brookmans Park transmitter, but on certain days, during which assessments were made in the intervening mush area (Fig. 9), AMC was also applied to Clevedon transmitter.

Starting from the premise that, for the use of AMC as a means of power saving to be acceptable, it must cause imperceptible loss in reception quality to the great majority of listeners, it was considered essential that the tests should allow immediate comparisons to be made between conditions with normal modulation and those with AMC applied. This

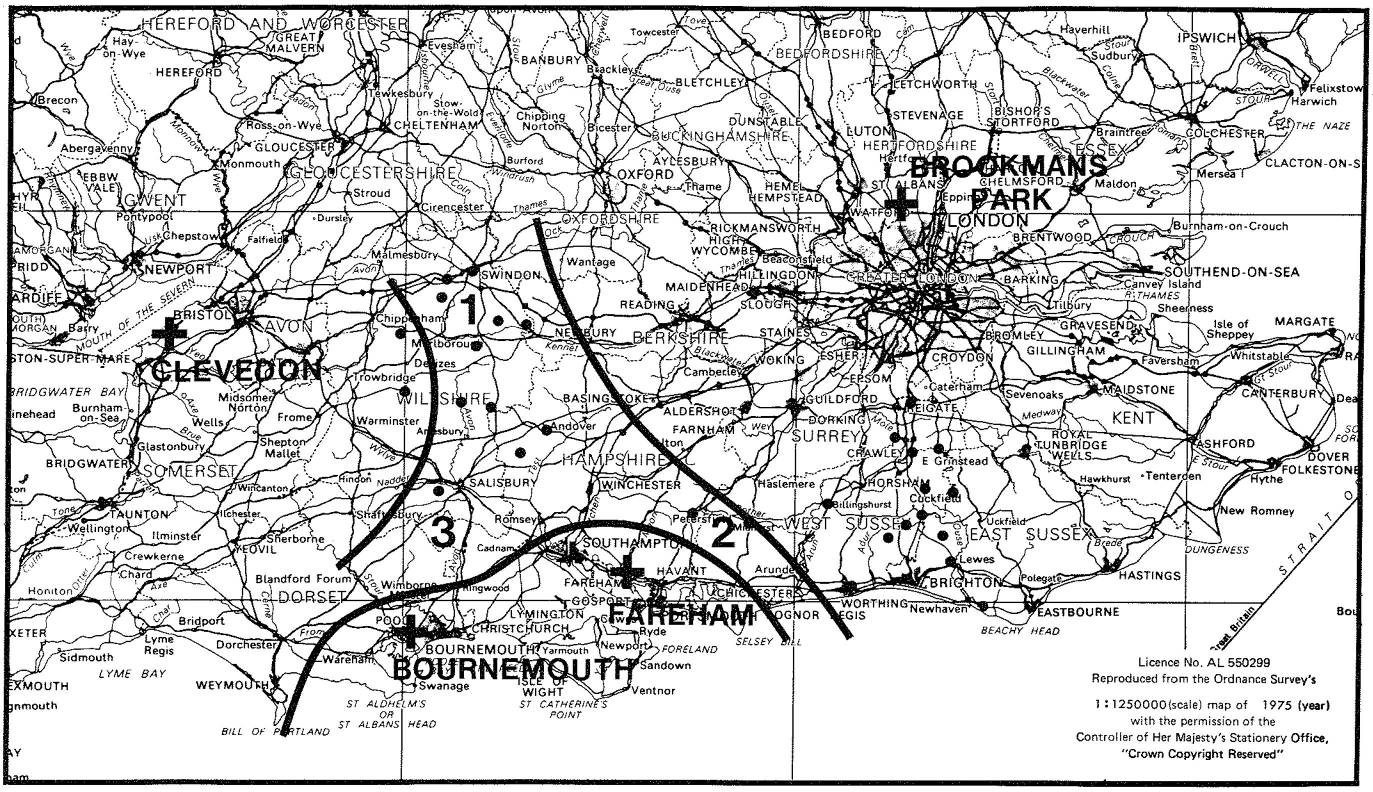


Fig. 9 - Map showing the area covered by the AMC field trials.

● Measurement/recording points.
▬ Nominal service limits of 909 kHz transmitters shown.
1 Mush Area Brookmans Park/Clevedon.
2 Mush Area Brookmans Park/Fareham.
3 Mush Area Brookmans Park/Clevedon/Fareham/Bournemouth.

precluded (from this stage of the trials) any modifications to the transmitter load impedances designed to improve efficiency when operating with AMC. However, it was considered that this would not affect the validity of subjective tests.

To enable the instantaneous comparisons to be made, control units were provided at both Brookmans Park and Clevedon giving, over a period of 5 minutes, ten seconds of normal modulation alternating with twenty seconds with AMC applied.

The daytime tests were carried out during one week, generally from 09.15 to 16.45 hours. The effects of night-time conditions were assessed during the following week, between 17.45 and 23.45 hours.

For the first two days the maximum compression of the AMC was set at 2.5 dB; this was subsequently increased to 3 dB for the remainder of the trial. An attack time of about 0.3 ms was used to operate the compressor, excepting for the final day of the daytime tests when this was extended to 5 ms, with a corresponding increase in the delay time.

6.2 Results

6.2.1 Assessment by Research Department

In this, two engineers travelled through various parts of the Brookmans Park coverage area, making subjective assessments and tape recordings, using battery operated receivers of varying quality and cost. Static assessments were made at some twenty-nine locations in daytime, and at a further ten locations after dark. These locations are indicated on Fig. 9. Additionally, the car radio receiver was used to make mobile assessments.

An edited version of the many recordings obtained was made to allow assessments to be made by a wider audience. However, the engineers involved observed no impairment attributable to AMC at any location on any receiver.

6.2.2 Assessment by other BBC staff

Although these trials were not formally publicized, it was considered that it would be helpful

to obtain some supplementary assessments from BBC staff. Accordingly, a questionnaire was distributed to a number of engineering staff asking for comparative gradings to be made for the two modulation conditions. The results were as follows:

(i) Number of assessment forms received 25

(ii) Number of receivers on which assessments were made 44

(iii) Number of listeners noticing no difference .... 22 (on 39 receivers)

(iv) Number of listeners who considered AMC to cause some impairment of reception quality .... 3 (on 5 receivers)

NOTE:

(a) One listener observed impairment during only one out of three periods of listening. This was observed on music only and classed as "just noticable if concentrating on it".

(b) A second listener noticed the impairment (graded as "slightly worse") as a reduction of signal on two home-made receivers of very basic design, neither of which incorporated AGC*. Impairment was not observed on a third, commercially made receiver.

(c) A third listener observed the impairment as resulting from an increase in man-made noise when listening in the presence of interference from, in one case, fluorescent lighting (graded as "slightly worse") and, in another case, television timebase harmonics (graded as "worse").

Subsequent attempts to simulate the same conditions in laboratory tests proved inconclusive.

6.3 Conclusions from field trials

1. There being no adverse response from any listeners to the edited tape recording, it seemed that introduction of AMC on Radio 2 with a maximum compression of 3 dB is unlikely to cause any perceptible quality impairment to the population as a whole. However, a very small proportion of expert listeners may be able to detect the difference on some sets, but probably only in a switched comparison.

2. The tests did not reveal any discernible differences between the two attack/delay times used. Since the shorter times presumably allow some minor additional power-savings, these would seem preferable. The shorter delay will also have a lesser effect upon reception in mush areas involving low power transmitters to which AMC may not be applied.

3. During the field trials, despite the differing AGC characteristics of the receiver used in the trials and shown in Appendix 1, no impairment of the received AMC signal which could be ascribed to receiver AGC was observed. The receivers tested are considered to be a fair cross-section of those in use domestically at the present time. It is therefore considered that with the amount of AMC envisaged no problems due to receiver AGC will occur.

* In view of the above, further AGC tests were carried out on the various receivers used for the field trials. These are discussed in Appendix 1.

7. EXPERIENCE OF OPERATIONAL USE AT BROOKMANS PARK

7.1 Objectives

Following the field trials discussed in the previous section, a pilot project was initiated to put AMC into operational use on some of the transmitters at Brookmans Park. The main objectives were to produce a properly engineered system that would:

- not reduce existing margins for maintenance.
- not make maintenance significantly more difficult.
- not degrade transmitter performance under conditions of varying load, power levels, mains voltage or environment.
- be quick and simple to install and set up.
- monitor transmitter performance automatically in terms of carrier reduction tracking and audio quality.
- allow fast and, if possible, instant restoration to conventional AM operation.
- assess the problems in applying AMC to multiple combined groups of transmitters.

7.2 Monitoring

An automatic monitoring system, compatible with that already in use on BBC MF transmitters had

to be devised. Normally this has been achieved by making an automatic comparison, over the working dynamic range, between input programme voltage and a sample of demodulated transmitter RF output. However with this arrangement, AMC introduces a comparator error because AGC cannot be employed at the monitoring demodulator without loss of carrier level error sensing. Furthermore, it is an operational requirement that the monitoring should check that the instantaneous RF carrier power is reduced by the correct amount in response to the input audio signal.

A new audio comparator, recently developed by the former Transmitter Capital Projects Department for use on HF and VHF transmitters, includes a facility to compensate for the effects of a limiter/compressor. Its characteristics were modified to match the linear compression curve of the AM6/30 AMC processor, and a small circuit board added to monitor RF carrier power reduction.

To avoid the need for extensive wiring within the transmitter, the DC voltage representing carrier power was routed to the comparator by a 'phantom' circuit, on the existing balanced audio line from the demodulator to the comparator.

Throughout the pilot project the modified comparators performed well using the normal ±4 dB window width. Tests were made with window widths down to only ±2 dB, so proving the principle; however because the same comparator is used to check both audio and carrier levels, a tendency was noted for interaction. It was agreed that, for full-scale implementation, a simplified version should be laid out with separate comparator circuits for the two functions, additional facilities to simplify setting up and the the elimination of a great deal of circuitry, redundant in this application.

7.3 Initial experience with Radio 1 transmitters

In May 1987, the three transmitters, which in parallel provide the Radio 1 service to listeners in the South East of England on 1089 kHz, from the Brookmans Park transmitting station, were each modified for AMC, using the method developed in the field trials. 3 dB compression was used together with the monitoring system described above. No adverse reaction at all was received from the public or from more critical specialist listeners.

Electricity consumption during the period was measured and agreed within 2% of that recorded in Section 5.6 for type P-1 material. It was noted at the time of installation, however, that transmitter performance was somewhat degraded, although it remained within specification. This degradation was less when the three transmitters were operated in parallel than for any one operating individually.

7.4 Experience with Radio 3 transmitter

Shortly after the Radio 1 transmitters had been put into service with AMC, the Radio 3 transmitter was similarly modified. Operational use had to be deferred, however, as the transmitter performance was found to be unacceptable in a number of respects:

a) The nominal carrier power could not be achieved under certain conditions.

b) Distortion figures were poor and in particular, cross-over distortion was evident which could not be trimmed out.

c) Performance was found to be variable and inconsistent.

The problems were eventually all traced to the simplistic method of applying AMC to the transmitter developed for the original field trials. AMC itself was not to blame.

A detailed analysis was undertaken which showed that:-

a) The carrier valve was being taken prematurely into 'saturation' on positive half cycles of modulation, resulting in a severe loss of efficiency. This was partially compensated for by the increased anode impedances mentioned earlier. The increased impedances were found to be responsible for the loss of carrier power in a) above and were in part responsible for the variability in performance and susceptibility to load variations, as well as being inconvenient and time-consuming to set up.

b) The point in the modulation cycle at which the peaking valve started to conduct and the carrier valve 'saturated' to compensate, were no longer always coincident (as they should be), but separated by varying degrees as the AMC control signal was applied. The 'turn-on' point of the peaking valve also became dependent upon the variabilities of the valve characteristics rather than the precision of the low-level operational amplifier circuit, as in normal operation.

The overall result was severe cross-over distortion, which could sometimes be partially com-

pensated for with the normal adjustments. However the slightest variation in load impedance, ambient temperature or mains voltage produced a different cross-over characteristic requiring different compensation.

These conclusions were confirmed by a re-test on the Radio 1 transmitters whose distortion performance was found to have degraded somewhat since AMC was installed. Furthermore, performance was found to be considerably poorer during the afternoon, when the mains voltage was a little higher.

As a result, it was decided to restore the transmitters to normal operation and defer the pilot trial, pending a solution to the problem. It was also clear that many of the conclusions and measurements obtained from the earlier trials, with the important exception of the subjective response, would be invalid.

7.5 Improved method of applying AMC to Marconi B6034 transmitters

It was fairly obvious from the analysis above that the problems could be resolved simply by applying the AMC control signal further back in the audio chain within the transmitter, before the point where the chain splits to process separately the drive signals for the two valves. In this way, the control signal would be processed in exactly the same manner as an audio signal in normal operation.

Preliminary tests were made at Brookmans Park and at Droitwich which were very encouraging. It was therefore decided to develop the modifications thoroughly and Designs Department Audio Section kindly provided laboratory space and advice. Within two weeks a detailed modification list had been developed and proven in the laboratory.

7.6 Anode impedances

Further analysis of the 'new' methods of operation showed that the conduction angle of the peaking valve would be so small with AMC applied at 3 dB, that its overall contribution to the transmitter output power would be minimal. Consequently its efficiency would be relatively insignificant to the overall transmitter efficiency. Calculations suggested that if the standard anode impedance of 475 ohms were retained, instead of the 950 ohms demanded for maximum efficiency, the overall transmitter efficiency would only be degraded by 1% or so.

The operational advantages of retaining standard anode impedances are immense, for instance:-

a) Instant switching between AMC and normal AM becomes possible.

b) Installation time is greatly reduced.

c) The transmitter should be no more susceptible to load impedance, mains voltage or temperature variations than normal.

d) Available headroom and margins are greatly increased.

e) The problem of insufficient available inductance for transmitters operating at the low frequency end of the band becomes irrelevant.

7.7 Tests on Radio 2 transmitter at Brookmans Park

A series of tests were then undertaken at Brookmans Park on one of the Radio 2 transmitters using the newly developed method of applying AMC. The tests were completely successful and demonstrated that:-

a) Standard anode impedances could indeed be retained with the new method of applying AMC. Measurements were made both with the optimum efficiency impedances and standard and these confirmed that a degradation of only 1-2% resulted from retaining the standard impedances. It was also found that the overall transmitter efficiency with standard impedances corresponded very closely with the best figures obtained in previous trials using the original method of applying AMC and the increased impedances this required.

b) Performance was stable, repeatable and no more susceptible to variations in load impedance, mains voltage, ambient temperature or valve ageing than under normal AM operation.

c) Distortion figures were similar to those obtained in normal AM operation.

d) Instant switching between AMC and normal was possible and no changes in any of the pre-set adjustments was necessary.

e) Instant switching between any of the levels of compression allowed by the AM6/30 was also possible with no ill effects or degradation in performance.

7.8 Resumption of pilot trial at Brookmans Park

As a result of the success of the tests on the Radio 2 transmitter, the pilot trial on the Radio 1 and Radio 3 transmitters at Brookmans Park was resumed, using the new method of applying AMC.

The three Radio 1 transmitters were duly modified and went into service with the 'new' AMC and 3 dB compression on the night of November 17th 1987. No problems were encountered and the recorded performance figures were comparable with the normal operation. The Radio 3 transmitter was modified and put into service at the same time, again with no problems.

7.9 Results of pilot trial

The pilot installation has remained in service since and no operational problems have been reported, neither have there been any complaints from listeners or other evidence of any reduction in service quality. The cumulative energy saving due to the use of AMC on these four transmitters is very much in line with the predicted figures, suggesting that the capital costs involved in modifying all the National Network high power MF transmitters would be recovered within less than six months.

8. APPLICATION OF AMC TO HF TRANSMITTERS

In principle AMC could be applied to HF transmitters in the manner already described, to obtain power savings with negligible loss of reception quality, whilst maintaining the same carrier power at low modulation levels. However it may be preferable to consider operating with an increased nominal carrier power to improve reception.

Previous work (see Table A2.3 of Appendix 2) has indicated that AMC with 6 dB maximum compression provides a lesser reduction in quality than 1.5 dB reduction in carrier power in an interference limited situation such as may be representative of difficult HF reception conditions. It may therefore be deduced that a 1.5 dB increase in carrier power associated with AMC at 6 dB maximum compression would provide a reception quality slightly better than conventional AM. For example, increasing the carrier power of a standard Marconi 300 kW PDM type HF transmitter by 1.5 dB would allow a 420 kW nominal output with AMC. Such operation remains to be proven and further work is being undertaken.

9. CONCLUSIONS

(i) The results of the various laboratory tests and field trials have indicated that the application of Amplitude Modulation Companding with a maximum compression of 3 dB on the BBC's MF transmitters will provide substantial power savings with negligible loss in reception quality even in fringe areas. This was subsequently confirmed on the basis of operational experience.

(ii) Transmitter tests have confirmed that operation with 3 dB AMC is possible over the full range of supply voltage variations and antenna impedance limits. Furthermore such operation does not require special test equipment or maintenance techniques. In some respects, e.g. protection against generation of spurious frequencies, the performance of transmitters modified to operate with AMC is improved.

(iii) There is scope for a further slight increase in efficiency. This can be obtained by increasing the anode impedances to the optimum required for the reduced Peak Envelope Power which results from the use of AMC. For a 50 kW transmitter with 3 dB compression, PEP is reduced from 200 kW in normal AM to only 100 kW. Increased impedances might be considered worthwhile for a 50 kW transmitter if AMC is adopted full-time.

(iv) Cost savings are likely to be somewhat greater than indicated by the percentage power savings in (ii) above due to a reduction in the 'capacity' and 'maximum demand' elements of the electricity tariff.

(v) A small increase (e.g. by 1 dB) above 3 dB in maximum compression is unlikely to achieve a worthwhile further power saving. However, if the compression is increased to 6 dB without otherwise changing the method of applying AMC, power savings in the range 27-48% are achievable. A variation on the 6 dB condition using a single valve (the carrier valve) and adjustment of the operating law to remove the delayed onset of compression, below 10% modulation, offers the possibility of further savings in the range 35-55%. However, only somewhat limited tests have been carried out for

AMC in excess of 3 dB. Nevertheless the comparison between AMC and static power reductions indicated that even under the condition least favourable to AMC (noise-limited), a maximum compression of 6 dB is subjectively equivalent to a fixed power reduction of only about 1.5 dB.

(vi) In principle, AMC may also be applied in HF broadcasting. Here the preference may be to use about 6 dB maximum compression associated with a small increase in nominal carrier power. Further work is in progress.

10. RECOMMENDATION

It is recommended that AMC with a maximum compression of 3 dB be applied throughout the National Networks, starting with Radio 1.

Subject to the absence of any unfavourable comment about the effect of this introduction, consideration should be given to carrying out further trials at a maximum compression of 6 dB to establish whether it is feasible to operate stations in the National Networks under this condition without loss of population coverage.

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APPENDIX 1

Effect of Receiver Automatic Gain Control

In view of the report of degraded reception by the listener using receivers without AGC in the course of the trials discussed in Section 6.2.2, those receivers used in the course of the field assessments were examined to establish the degree of effectiveness of their AGC under low field strength conditions. This was done by applying a field strength of 5 mV/m in the form of a tone modulated carrier, then reducing this in steps of 5 dB whilst measuring the audio output with a sound level meter. The results so obtained are indicated in Table A1.1 below.

Table A1.1: Output sound levels from receivers as a function of applied field strength

Change in field strength (dB) relative to reference of 5 mV/m	−5	−10	−15	−20	−25
RECEIVER MODEL	Change in o/p level (dB) for specified change in field strength				
A	−0.4	− 0.8	− 1.0	− 1.4	− 4.4
B	−0.6	− 1.0	− 1.9	− 3.0	− 4.7
C	−1.0	− 2.2	− 5.2	−10.2	−16.0
D	−4.0	− 9.0	−15.0		
E	−4.0	− 9.0	−14.0		
F	−0.6	− 1.4	− 2.6	− 4.7	− 8.0
G	−5.0	−11.0	−17.0		

As may be seen, even this limited choice of receivers provided a wide range of AGC performance ranging from the negligible (D, E, and G) to the very good (A and B).

Subsequent laboratory tests were carried out in which it was possible to switch from normal modulation to AMC at variable maximum compression levels of up to 10 dB. These indicated, not surprisingly, that at input field strengths of the order of 1 mV/m and a high degree of compression, the use of AMC resulted in significantly greater levels of receiver noise on receivers with poor AGC performance. However, with the 3 dB maximum compression level as used in the field trials this increase was considered imperceptible even on the receivers with poor AGC performance.

APPENDIX 2

Results of Subjective Tests Comparing AMC with Fixed Power Reductions

(taken from Reference 2)

A2.1 General

The following test procedure was carried out individually by twelve listeners, each using his own domestic portable receiver, which was installed in a double layer mesh cage within which a known field strength could be generated. Two 10-position switches were provided by which the listeners could either:

a) reduce the wanted signal field strength in steps of approximately 1 dB under the normal modulation conditions or,

b) apply AMC in steps of approximately 1 dB increase in maximum compression.

These were termed the 'C' and 'D' controls respectively.

A2.2 Subjective test conditions

To reduce the effort required in the subjective investigation to manageable proportions, tests were carried out under only three different reception conditions:-

a) in a 15 mV/m field strength, without added interference;

b) in a 15 mV/m field strength, with a locked co-channel interfering carrier at a protection ratio of 26 dB, fully modulated by a 'Pop' music programme signal, processed for MF transmission;

c) in a 2 mV/m field strength without added interference.

15 mV/m and 2 mV/m field strengths were chosen to represent typical service limits for night-time and day-time reception respectively. The 26 dB protection ratio represents the least-favourable limit for co-channel interference proposed for service planning purposes in CCIR Report 794.

The restriction of the form of interference to locked co-channel was only imposed arbitrarily for economy of effort. However, to make the tests as stringent as possible a carrier phasing close to 180 degrees, the least favourable condition, was adopted.

Three test programme items were initially chosen as likely to constitute stringent test material, speech, soprano singing and piano, these being processed for an MF AM service carrying predominantly classical music. In the light of the results obtained for these items, tests were carried out subsequently on a further speech item which was processed for a service carrying a range of programme types, to represent the more critical contents of such a service.

A2.3 Subjective test procedure

At the beginning of each test session each listener was advised that programme quality degradation might at times be present.

His attention was drawn, for example, to the possibility of impairment due to noise or interference effects — either steady in level or programme modulated — and to possible disturbance of the relative levels within a programme signal. He was asked to take all forms of impairment into account, and to base his assessments on the overall effects. He was not informed of the test details or of the significance or the effect of the controls which he was required to operate during tests. But he was being asked, in effect, to make the comparison gradings and apparatus adjustments described below (not necessarily in the order given) for each test programme item.

The test sequence was as follows:-

1. With the receiver in a 15 mV/m field strength and without interference:

(a) Grade an assessment of the AMC system, with Law D10 in operation, relative to that for a conventional system with no output reduction, i.e. C0 (identical quiescent carrier levels), using the 7-point CCIR comparison scale shown in Table A2.1. Note grade.

Table A2.1: CCIR 7-point comparison scale

GRADE	COMPARISON
+3	B much better than A
+2	B better than A
+1	B slightly better than A
0	B same as (or equivalent to) A
−1	B slightly worse than A
−2	B worse than A
−3	B much worse than A

(b) If D10 is graded as inferior to C0, adjust the 'D' control (to reduce the amount of dynamic compression) until the 'D' condition is "just perceptibly" worse than the 'C' condition. Note the position of the 'D' control.

2. With the receiver in a 15 mV/m field strength and with 'pop' music modulated co-channel interfering signal at a protection ratio of 26 dB:-

   (a) as 1(a)

   (b) as 1(b)

   (c) Leaving the 'D' control as set in 2(b) adjust the 'C' control until the 'C' condition is now "just perceptibly" worse than the 'D' condition. Note setting of the 'C' control.

3. As 2, but in a 2 mV/m field strength and without interference.

These tests were carried out for the various test items noted above.

A2.4 Test results

The mean scores and standard deviations for the various tests are listed in Table A2.2 under the test condition categories given in Section A2.2.

Table A2.2
Subjective Assessments: Control settings corresponding to impairments imperceptible to 50% of listeners

Test		Grading/control setting (Standard Deviation) Soprano (P3)	Piano (P3)	Speech (P3)	Speech (P2)
15mV/m, no interference	1(a) Rel. Grading	−0.17 (0.33)	+0.04 (0.66)	−0.29 (0.58)	−0.04 (0.14)
	(b) 'D' setting, dB	>9.28 (1.76)	>9.83 (0.92)	>9.13 (1.77)	>10.0
15mV/m, with Radio 1 ('pop') modulated co-channel interference	2(a) Rel. Grading	−0.42 (0.63)	−0.92 (0.56)	−0.25 (0.40)	−0.58 (0.47)
	(b) 'D' setting, dB	>9.08 (1.52)	>7.45 (1.81)	>9.37 (1.50)	>9.43
	(c) 'C' setting, dB	3.98 (1.51)	4.48 (1.59)	3.81 (1.47)	4.24 (1.64)
2mV/m, no interference	3(a) Rel. Grading	−1.02 (1.00)	−2.14 (0.67)	−1.36 (0.95)	−2.04 (0.69)
	(b) 'D' setting, dB	>7.54 (2.9)	5.20 (2.17)	>6.13 (3.08)	4.80 (0.91)
	(b) 'C' setting, dB	3.14 (0.74)	3.47 (0.70)	2.92 (1.26)	3.23 (0.98)

In the present context, however, a system performance corresponding to a mean grading figure would not be acceptable in practice since it implies that about half those listening would have given a worse grading, albeit only under adverse reception conditions and on critical programme items.

A second listing of results is given therefore in Table A2.3, showing system performance parameters corresponding to a 90% satisfaction under the conditions of the test. This latter analysis was based on an assumption of a Normal Distribution of results, and it is encouraging to note that, of all the individual results analysed, a total of 11% actually fell outside the 90% satisfaction* groups for the performance standards thus defined — a figure very close to the theoretical value of 10%.

* The instruction to listeners to set the equipment controls to obtain "just perceptibly worse" conditions implies marginally less than 90% of listeners being unaware of any degradation. However, in practical conditions, where the reference condition is not available for comparison, more than 90% would be expected to be unaware of any degradation.

Table A2.3
Subjective Assessments: Control settings corresponding to impairments imperceptible to 90% of listeners

	Test	Soprano (P3)	Piano (P3)	Speech (P3)	Speech P2)
15 mV/m, with Radio 1 ('pop') modulated co-channel interference	2(b) 'D' setting, dB	7.13	5.13	7.45	8.35
	(c) 'C' setting, dB	2.05	2.44	1.93	2.14
2 mV/m, no interference	3(b) 'D' setting, dB	3.83	2.42	2.19	3.64
	(c) 'C' setting, dB	2.19	2.57	1.31	1.98

N.B. The attenuation represented by the 'C' setting corresponds to the change from a condition "just perceptibly better than" and setting 'D' to "just perceptibly worse". Hence for equivalent impairment to setting 'D' the value of 'C' should be halved.

In some of the (b) test conditions one or more listeners found no fault with the D10 condition (i.e. Grade 0), implying that a range of AMC greater than the 10 dB provided might also have been acceptable to them. Their 'D' control setting for the corresponding (b) test has however been taken as D10 for analysis and cases where this occurred have been indicated in Table A2.2 by a 'greater than' sign preceding the mean figure in the (b) row concerned.

A2.5 Interpretation of test results

The most obvious point of note in Table A2.2 is the negligibly small adverse grading of the AMC system under good reception conditions, even with the 10 dB maximum compression law in use. This result is due to a perhaps surprisingly effective expanding action in the majority of receivers, and indicates that disturbance of programme dynamics is most unlikely to be a significant source of degradation in good reception conditions, particularly at the lower degrees of compression more likely to be adopted in practice.

The negative assessment gradings of the AMC system under adverse reception conditions, up to −2.04, reflect the effect of programme-modulated noise and interference, and possibly of inadequate expander action in some of the low signal-level tests. However, such results are not unexpected at the maximum degree of compression provided, and the following analysis is directed towards examining operating parameters giving impairment imperceptible to 90% of the listeners under the condition of the test.

The performance parameters listed in Tables A2.2 and A2.3, rows 2(b) and 3(b), are those estimated for dynamic control to give impairment "just perceptibly worse" than that of the reference conventional system under the conditions of the tests, while the figures given in rows 2(c) and 3(c) indicate amounts of static power reduction giving performance standards just perceptibly worse than those defined in 2(b) and 3(b) for AMC. We thus have determined two conditions of static operation, one at full level (i.e. no attenuation) and one at reduced level, giving respectively standards of performance "just perceptibly better" and "just perceptibly worse" than that of the AMC system at the degrees of compression just defined.

Hence a good indication of the static power reduction which is subjectively equivalent to the AMC condition giving impairment imperceptible to either 50% of listeners (Table A2.2) or 90% of listeners (Table A2.3) is obtained by taking half the values specified in rows 2(c) and 3(c).

APPENDIX 3

Transmitter Operation with 6 dB AMC

With 6 dB AMC applied, the carrier power and the peak envelope power are the same. This implies that a single valve (the carrier valve) could provide all the power required. A step improvement in efficiency would result, as the peaking valve with its filament and other losses could be eliminated.

Consideration of the characteristics of the AMC system show that, because compression is inhibited during the transition from 0% to 10% modulation, the peak envelope voltage rises above the carrier level until 10% modulation and then falls back to carrier level at 100%. This small rise in output requires a reduction in anode impedance to prevent clipping, which in turn causes a loss of efficiency at carrier level. (Fig. A3.1.)

Should 6 dB compression be adopted, then consideration should be given to dispensing with the 10% compression threshold to allow single valve operation. Limited tests were made with the theshold removed, and no discernible subjective difference could be detected. In the interim, 6 dB operation is quite acceptable with both valves fitted and the anode impedances unchanged. (Fig. A3.2.)

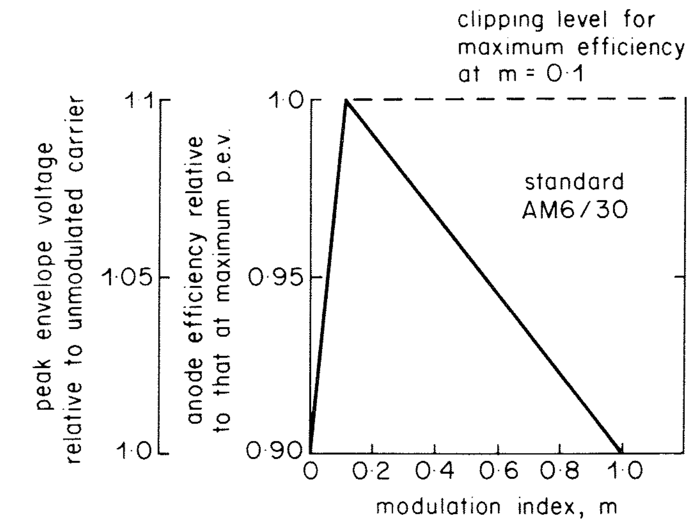

Fig. A3.1 - Illustrating 6 dB compression, relative efficiency and peak envelope power (p.e.p.). Note: clipping only occurs at m = 0.1.

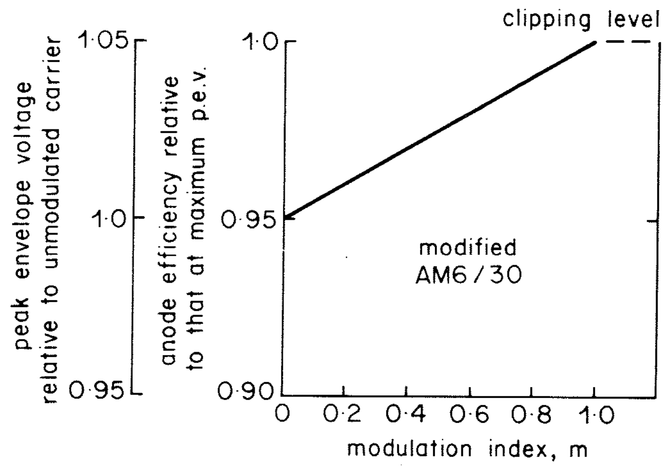

Fig. A3.2 - Illustrating 5.5 dB compression. This offers higher relative efficiency at m = 0 and no clipping until m = 1, i.e. the margin for changes in operating conditions is improved.

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